

Preface to special section on East Asian Studies of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE)

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[1] Papers published in this special section report findings from the East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE). They are concerned with (1) the temporal and spatial distributions of aerosol loading and precursor gases, (2) aerosol single scattering albedo (SSA), (3) aerosol direct radiative effects, (4) validation of satellite products, (5) transport mechanisms, and (6) the effects of air pollution on ecosystems. Aerosol loading is heaviest in mideastern China with a mean aerosol optical depth (AOD) of 0.5 and increasing to 0.7 around major cities that reduced daily mean surface solar radiation by $\sim 30\text{--}40\text{ W m}^{-2}$, but barely changed solar reflection at the top of the atmosphere. Aerosol loading, particle size and composition vary considerably with location and season. The MODIS AOD data from Collection 5 (C5) agree much better with ground data than earlier releases, but considerable discrepancies still exist because of treatments of aerosol SSA and surface albedo. Four methods are proposed/adopted to derive the SSA by means of remote sensing and in situ observation, which varies drastically with time and space. The nationwide means of AOD, Ångström exponent, and SSA ($0.5\text{ }\mu\text{m}$) in China are 0.69 ± 0.17 , 1.06 ± 0.26 , and 0.89 ± 0.04 , respectively. Measurements of trace gases reveal substantial uncertainties in emission inventories. An analysis of aircraft measurements revealed that dry convection is an important mechanism uplifting pollutants over northern China. Model simulations of nitrogen deposition and impact of ozone pollution on net primary productivity indicate an increasing threat of air pollution on the ecosystem.

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1. Motivation of the EAST-AIRE

[2] A key to understanding the direct and indirect radiative forcing of aerosols, which are the largest uncertainties in climate research [*Intergovernmental Panel on Climate Change*, 2007], is quantitatively characterizing aerosol properties on a region-by-region basis because both aerosol loading and properties exhibit drastic spatial and temporal variations. East Asia is a region where high aerosol concentrations are common, as is clearly shown by the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) product [*Kaufman et al.*, 2002;

Z. Li et al., 2007a], as well as from ground-based observations [*Nakajima et al.*, 2003]. According to worldwide systematic measurements of AOD from the Aerosol Robotic Network (AERONET) [*Holben et al.*, 1998], the annual mean AOD in east Asia and Asia as whole is about 0.36, ranking second highest in the world next to Africa (Table 1). Coexistence of dust, industrial pollutants, and smoke over this vast area complicates satellite retrievals [*Li*, 2004]. At present, there are few ground stations measuring aerosol loading and properties in most of the world's aerosol-laden regions, including Asia.

[3] Increasing evidence suggests that the influence of aerosols on the energy and water cycles of the Earth's system is significant [*Ramanathan et al.*, 2001]. Atmospheric circulation may be altered which influences monsoons [*Lau et al.*, 2006; *Lau and Kim*, 2006] and severe storms [*Zhang et al.*, 2007]. Despite the rapid increase in the number of studies dealing with aerosol issues in recent years, it remains a daunting task to determine the extent of the influence exerted by aerosols, especially those produced by human activities, on weather, climate and ecosystem. Unraveling this question is urgent in this heavily populated and rapidly developing region of the world, where more than half of the world's population resides. Changes in weather patterns and climate would affect the well being of billions of people.

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Table 1. Long-Term and Regional Means of Aerosol Optical Depth (AOD) and the Ångström Exponent Measured in Different Continental Regions of the World From the AERONET

Region	Africa	Asia	Australia	Europe	North America	South America
AOD	0.44	0.36	0.11	0.21	0.15	0.22
AE	0.62	1.11	0.87	1.27	1.34	1.17

[4] Over the past few decades, the climate in China has changed at an unprecedented rate. Perhaps the change most noticeable to the general public is a 35% reduction in visibility from the 1960s to the 1980s. During this period, the amount of direct solar radiation reaching the ground decreased by about 8.6% in China [Luo *et al.*, 2000; Liang and Xia, 2005], while total solar radiation decreased by about 4.6% per decade [Shi *et al.*, 2007]. The decrease in solar radiation reaching the ground is at odds with a general decreasing trend in annual mean cloud cover (1–3%/decade) and rainy days (1–4%/decade) observed at most ground stations in central, eastern, and northeastern China [Kaiser, 1998; Liang and Xia, 2005], which is consistent with an analysis using the more reliably observed frequencies of cloud-free sky and overcast sky [Qian *et al.*, 2006]. Using direct radiation measurements made at the surface, Luo *et al.* [2001] inferred a general increase in AOD of about 25% from 1960s to 1980s. This increase in AOD is likely the major cause for the cooling trend in central eastern China, while the rest of the country experiences significant warming [Xu *et al.*, 2006]. Changes in patterns of precipitation are also considerable with a general tendency of “south wetting and north drying.” On the basis of model sensitivity tests, Menon *et al.* [2002] hypothesized the observed change in the precipitation pattern were caused by the aerosol direct effect. However, they had to assume an aerosol single scattering albedo (SSA) of 0.85. This assumed value is lower than the majority of those estimated from ground and satellite measurements across China [Lee *et al.*, 2007].

[5] The aerosol direct effect may contribute to the weakening of the Asian monsoon system. Analyzing wind data in China, Xu *et al.* [2006] found that the surface wind speed associated with the east Asian monsoon has significantly weakened in both winter and summer seasons during the past three decades. From 1969 to 2000, annual mean wind speeds over China have decreased steadily by 28%, and the prevalence of windy days (daily mean wind speed >5 m/s) has decreased by 58%. They also found that the monsoon wind speed to be highly correlated with incoming solar radiation at the surface, which is very sensitive to aerosol loading.

[6] These changes in monsoonal winds are not surprising because the monsoon circulation is mainly driven by differential heating between the land and ocean. The dimming effect of aerosols [Wild *et al.*, 2005] reduces the inhomogeneous heating between land and ocean, and thus diminishes the temperature difference, which helps weaken the monsoon [Lau *et al.*, 2007]. The weakening of the east Asian monsoon system tends to decrease water vapor transport from the south to the north, prolonging the rain belt in the south, and reinforcing the trend of “south wetting and north drying.”

[7] Fewer investigate aerosol semi-indirect and indirect effects on cloud and precipitation because of the dearth of in situ measurements of coincident aerosol and cloud proper-

ties in this part of the world. Analyzing long-term trends of precipitation and sounding data along with short-term trends of MODIS AOD, Zhao *et al.* [2006] argued that the reduction in rainfall is caused by increasing atmospheric stability due to aerosol-induced heating of the atmospheric boundary layer, and proposed a positive feedback: more aerosols → less precipitation → more aerosols. The aerosol indirect effect was examined using MODIS aerosol and cloud products in China and other parts of the world [Li and Yuan, 2006; Yuan *et al.*, 2007]. They found that aerosols tend to reduce cloud particle size in northern China but increase cloud particle size in southern China. This finding agrees with Storelvmo *et al.* [2006] who investigated the aerosol indirect effect using the Global Climate Model CAM-Oslo. Rosenfeld *et al.* [2007] reported a correlation between rainfall reduction and air pollution over a hilly region in western China, and thus proposed that pollutant aerosols decreased cloud droplet size and reduced precipitation in that region.

4. Summary

[38] East Asia with China at its heart is one of major aerosol source regions in the world. While aerosols of natural origin (e.g., dust) continue to be a severe problem for this area, particles of anthropogenic origin (e.g., sulfates) have significantly increased over the past few decades. Aerosol impacts are likely substantial, but these effects are not well identified or quantified because of insufficient knowledge and understanding of the interactions of aerosols with ecosystems and climate.

[39] Through a cooperative research endeavor between Chinese and American institutions, a coordinated observation program was initiated, providing continuous high-quality measurements across China. It consists of twenty stations and two supersites making measurements on a routine basis over diverse climate zones and ecosystems within China. Intensive ground-based and airborne observation campaigns augmented the observational database. Some major findings during the first 3 a of the EAST-AIRE are reported in this special section. While previous observations confirm the existence of a haze layer over eastern China, the extensiveness of the EAST-AIRE network provides more detailed information about the temporal and spatial features of key aerosol properties and precursor gases. Simultaneous measurements of aerosols and irradiance has enabled the quantification of aerosol radiative effects, as well as development of few new SSA retrieval algorithms. Expanding high-quality ground-based aerosol observation networks (AERONET and CSHNET) to different regions in China enabled validation of and improvements in satellite retrievals useful for climate and ecosystem modeling. The vertical profiling capabilities of lidar and instrumented aircraft added to our knowledge of the vertical variations of aerosols and precursor gases essential for investigating aerosol effects on atmospheric stability and understanding the mechanisms of pollutant transport. Case studies with aircraft data shed some light on the potential role of dry convection on long-range transport of pollutants over east Asia. Aircraft-measured SO₂ profiles also helped improve satellite retrievals of this important pollutant. The effects of aerosols and trace gases on ecosystems and the carbon cycle were estimated using observational data. Satellites detected prominent urban heat island effects over Beijing, which was attributed to changes in the land surface due to the process of urbanization.